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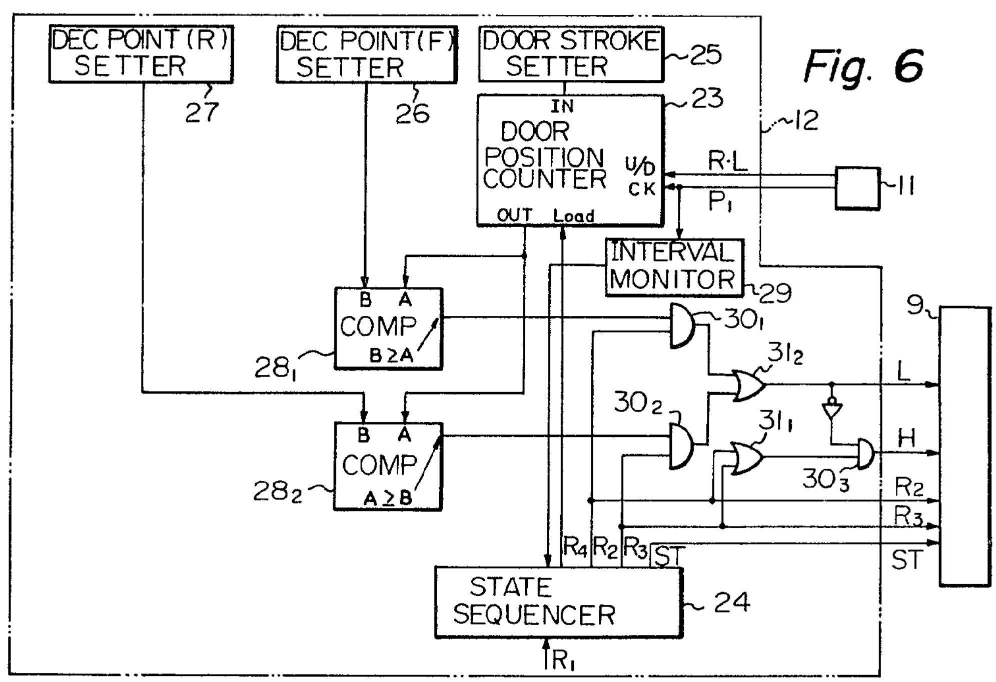
(71) Applicant
Yoshida Kogyo KK (Japan)
1 Kanda Izumi-cho
Chiyoda-ku
Tokyo
Japan

(72) and (74) continued overleaf

(54) Automatic control apparatus for door

(57) Apparatus for controlling the operation of an automatic door has a motion sensor directly coupled to the door which generates pulses having a pulse repetition rate proportional to velocity of the movement of the door driving member. Counter means (23) counts these pulses thus deriving the current position of the door which does not include any error arising from a loss or slip in an intermediate transmission mechanism coupling a motor with the door driving member. A pair of opto-electronic motion sensing elements are used to generate first and second series of pulses in response to the movement of the door. The phase relationship between the pulse trains defines the direction of the movement of the door, thus simplifying the sequence logic required. Further, a pulse interval monitor (29) is provided to generate a signal indicative of a relatively long lapse of time between pulses and operates a sequence control circuit to generate a stop command for the motor, thus preventing the overheating thereof in case the transmission mechanism from the motor to the door is accidentally disconnected. On each operation of the door a deceleration point setter 26, 27 calculates the point at which deceleration should start, to provide only minimal creep speed running regardless of the loading on the door.



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(72) Inventors
Yukio Yoshida
Kenzo Oono
(74) Agent and/or Address for Service
Marks and Clerk
57-60 Lincoln's Inn Fields
London WC2A 3LS

Fig. 1

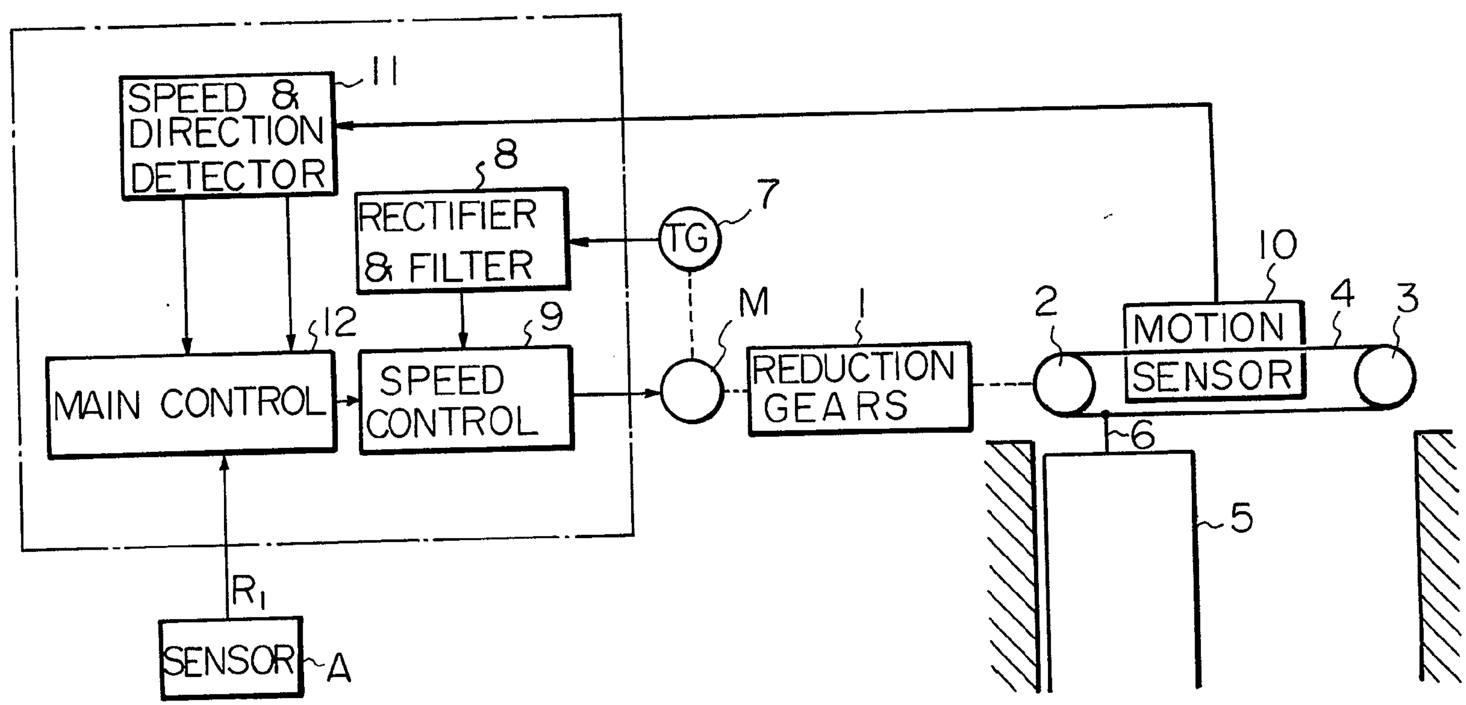
SPEED & DIRECTION DETECTOR
11
RECTIFIER & FILTER
8
TG
7
MAIN CONTROL
12
SPEED CONTROL
9
M
REDUCTION GEARS
1
2
MOTION SENSOR
10
4
3
6
5
R1
SENSOR
A

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Fig. 2

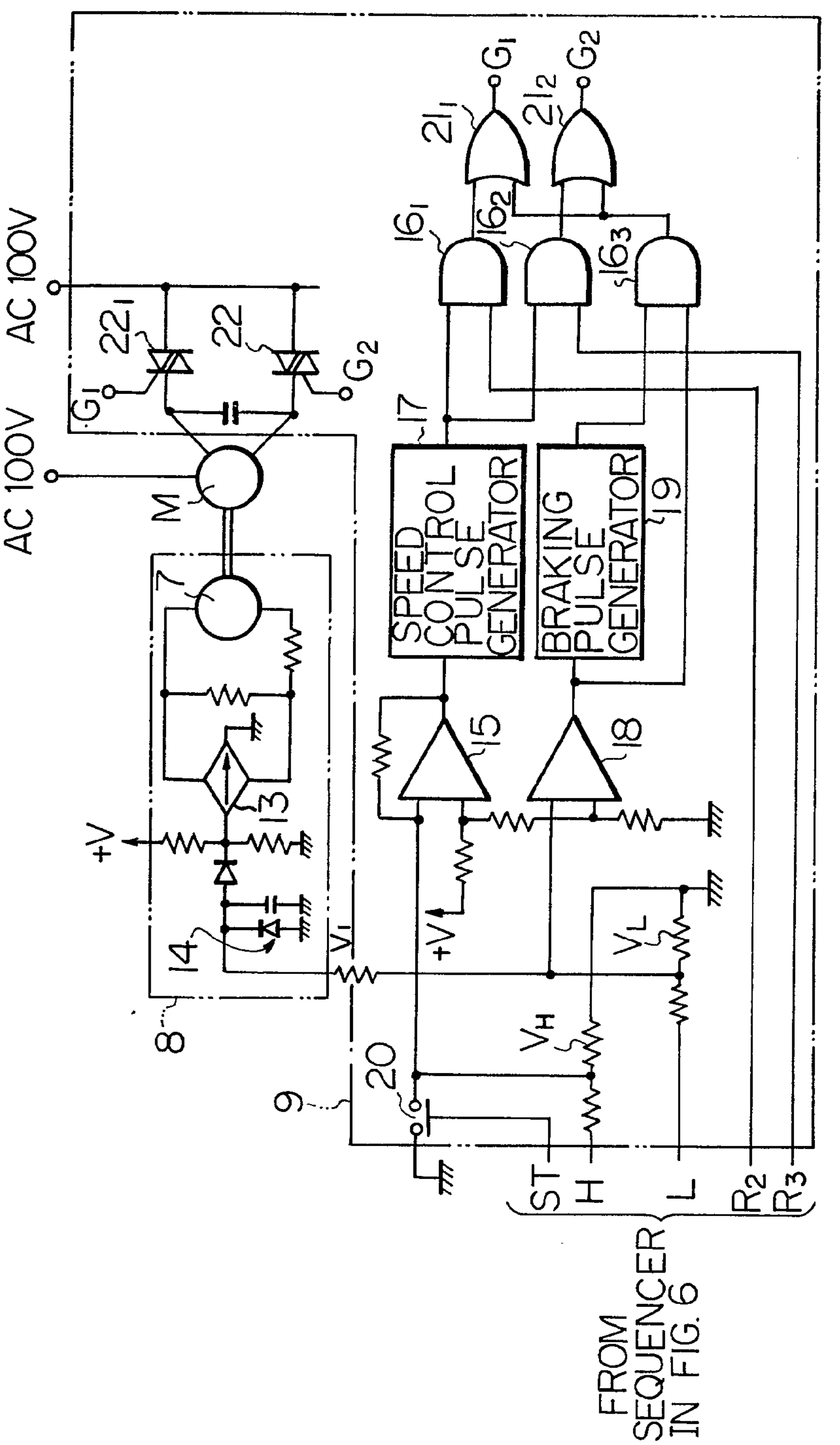


Fig. 3

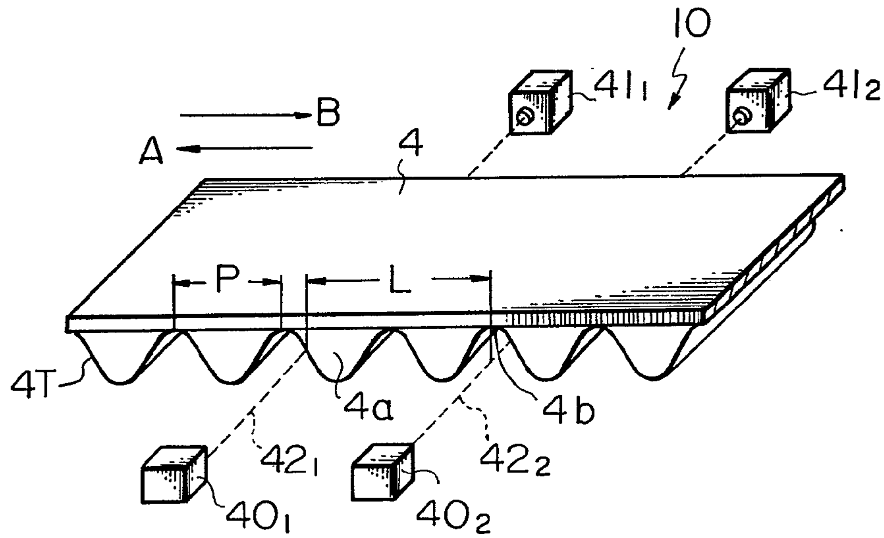

10
41_1
41_2
B
A
4
P
L
4T
4a
4b
42_1
42_2
40_1
40_2

Fig. 4

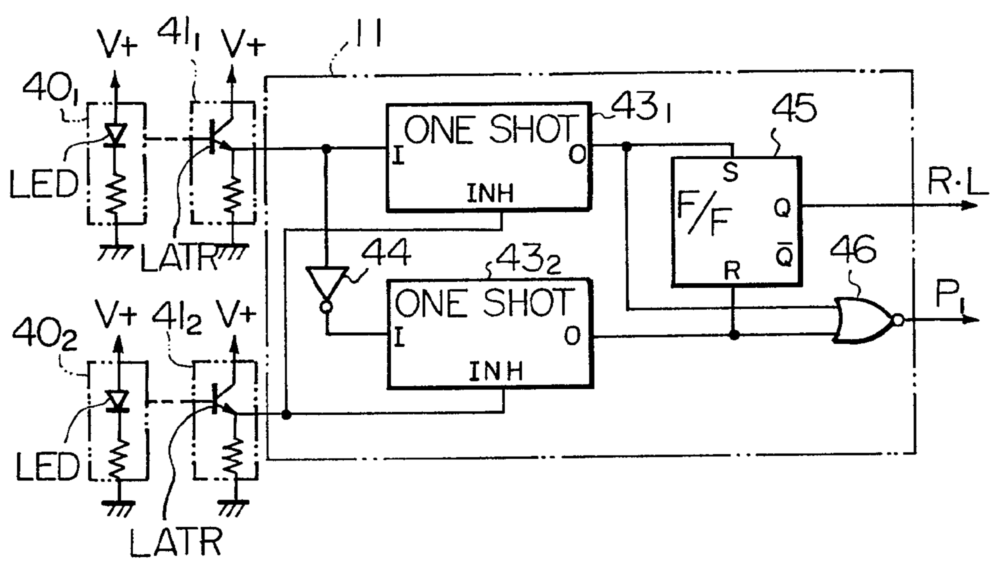

V+
41_1
V+
11
40_1
LED
LATR
ONE SHOT
I
O
INH
43_1
45
S
F/F
Q
R
$\bar{Q}$
R·L
44
43_2
46
ONE SHOT
I
O
INH
P_1
40_2
V+
41_2
V+
LED
LATR

Fig. 5

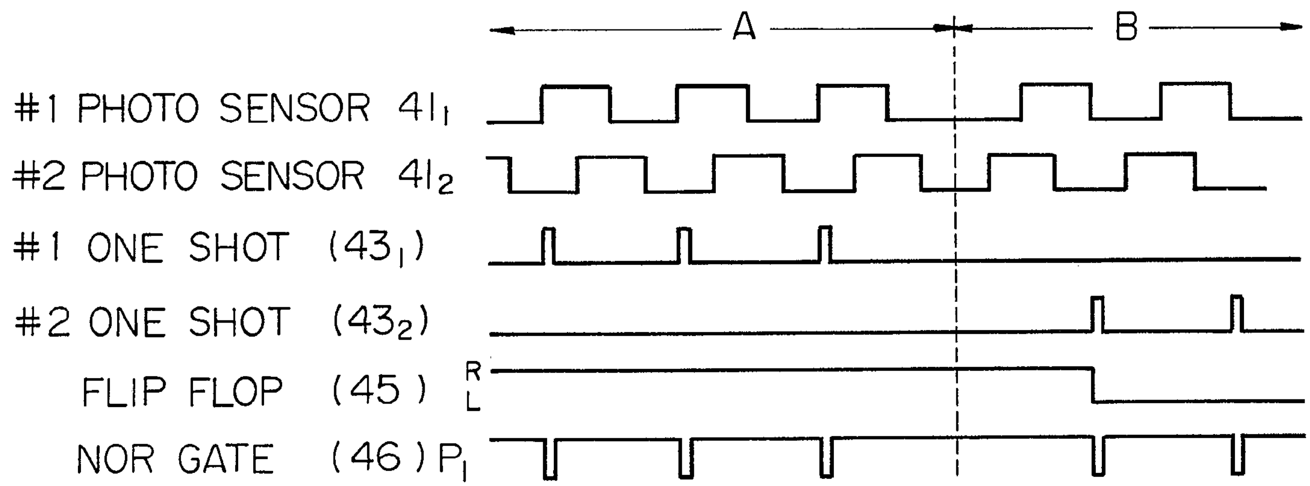
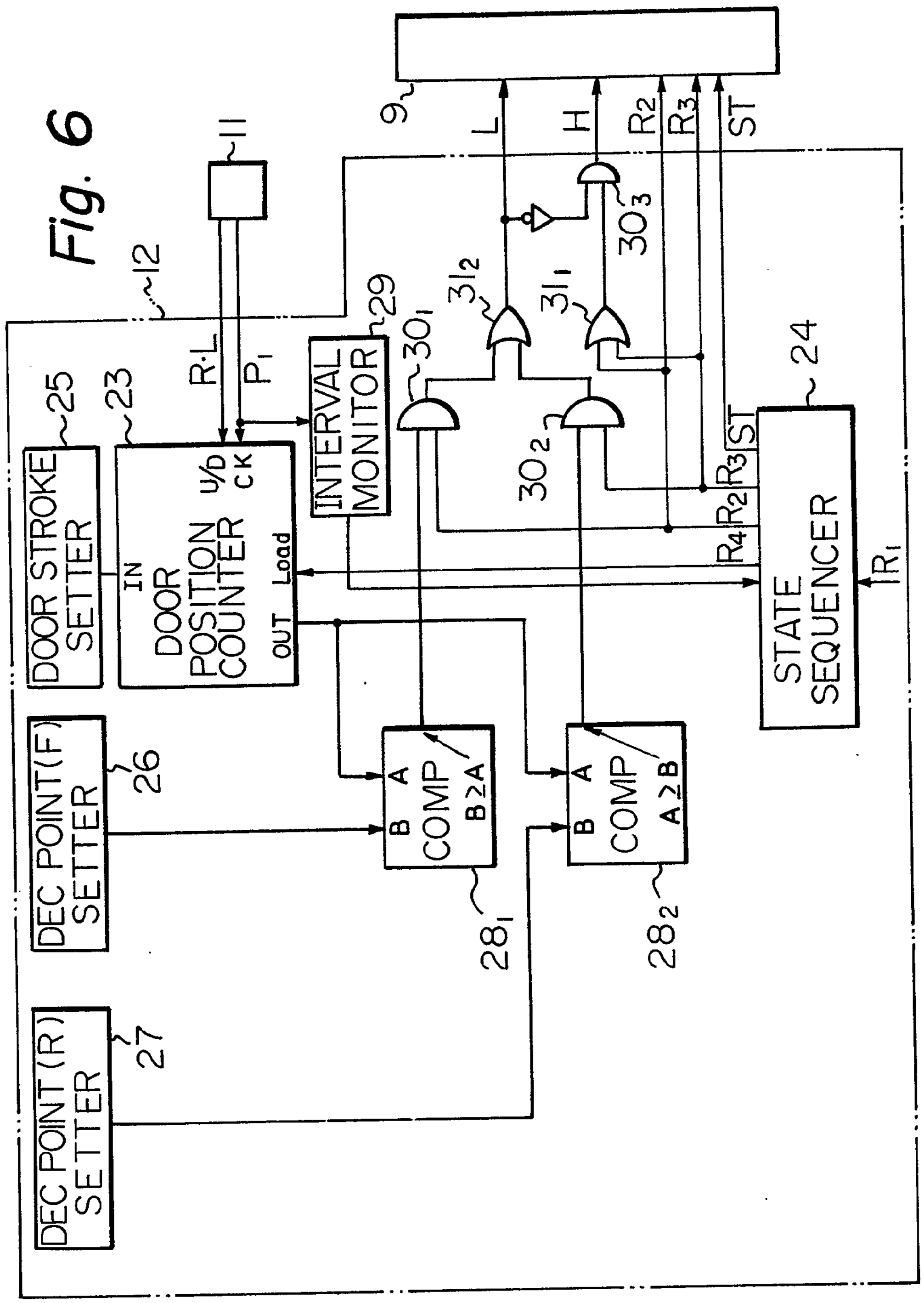

A
B
#1 PHOTO SENSOR 41_1
#2 PHOTO SENSOR 41_2
#1 ONE SHOT (43_1)
#2 ONE SHOT (43_2)
FLIP FLOP (45)
R
L
NOR GATE (46) P_1

Fig. 6



DOOR STROKE SETTER
25
23
IN
DOOR POSITION COUNTER
U/D
CK
Load
OUT
R·L
P1
11
12
INTERVAL MONITOR
29
DEC POINT(F) SETTER
26
DEC POINT (R) SETTER
27
B A COMP B≥A
28₁
B A COMP A≥B
28₂
30₁
30₂
30₃
31₁
31₂
STATE SEQUENCER
24
R1
R2
R3
R4
ST
L
H
9

C.

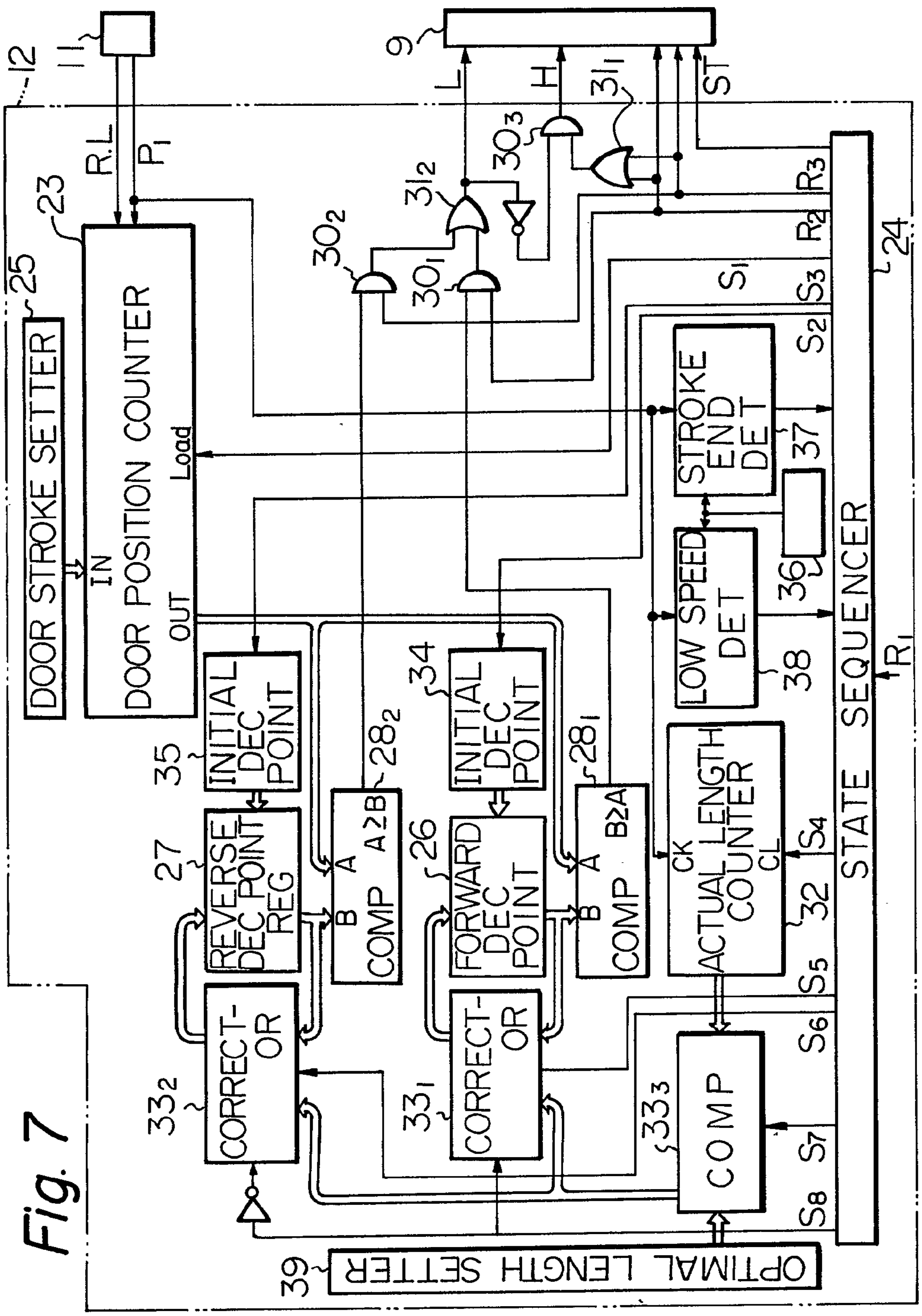

DOOR STROKE SETTER
DOOR POSITION COUNTER
IN
OUT
Load
R.L
P1
L
H
ST
INITIAL DEC POINT
REVERSE DEC POINT REG
COMP A≥B
FORWARD DEC POINT
COMP B≥A
CORRECT-OR
CORRECT-OR
COMP
LOW SPEED DET
STROKE END DET
ACTUAL LENGTH COUNTER CL
CK
STATE SEQUENCER
OPTIMAL LENGTH SETTER

Fig. 7

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Fig. 8

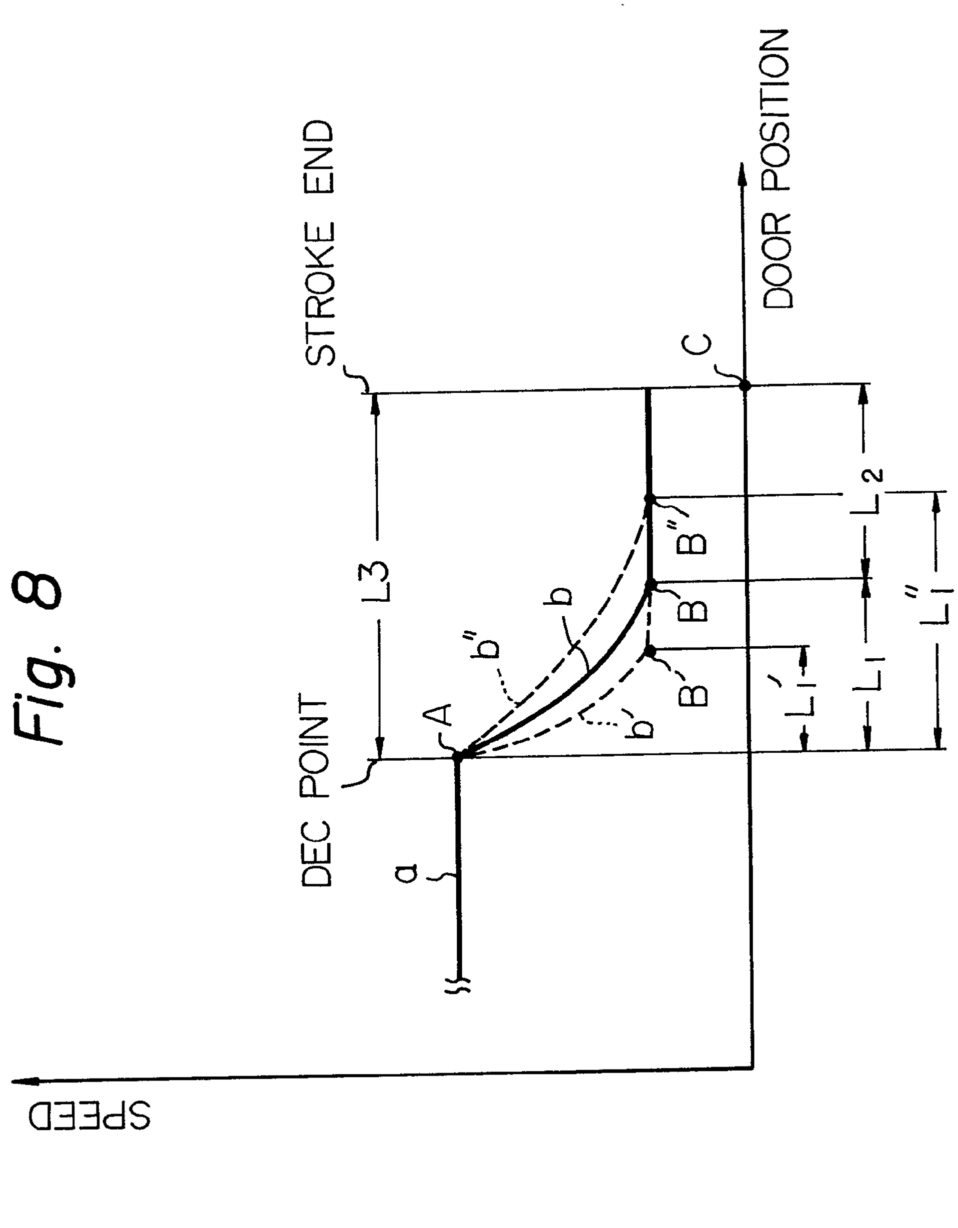
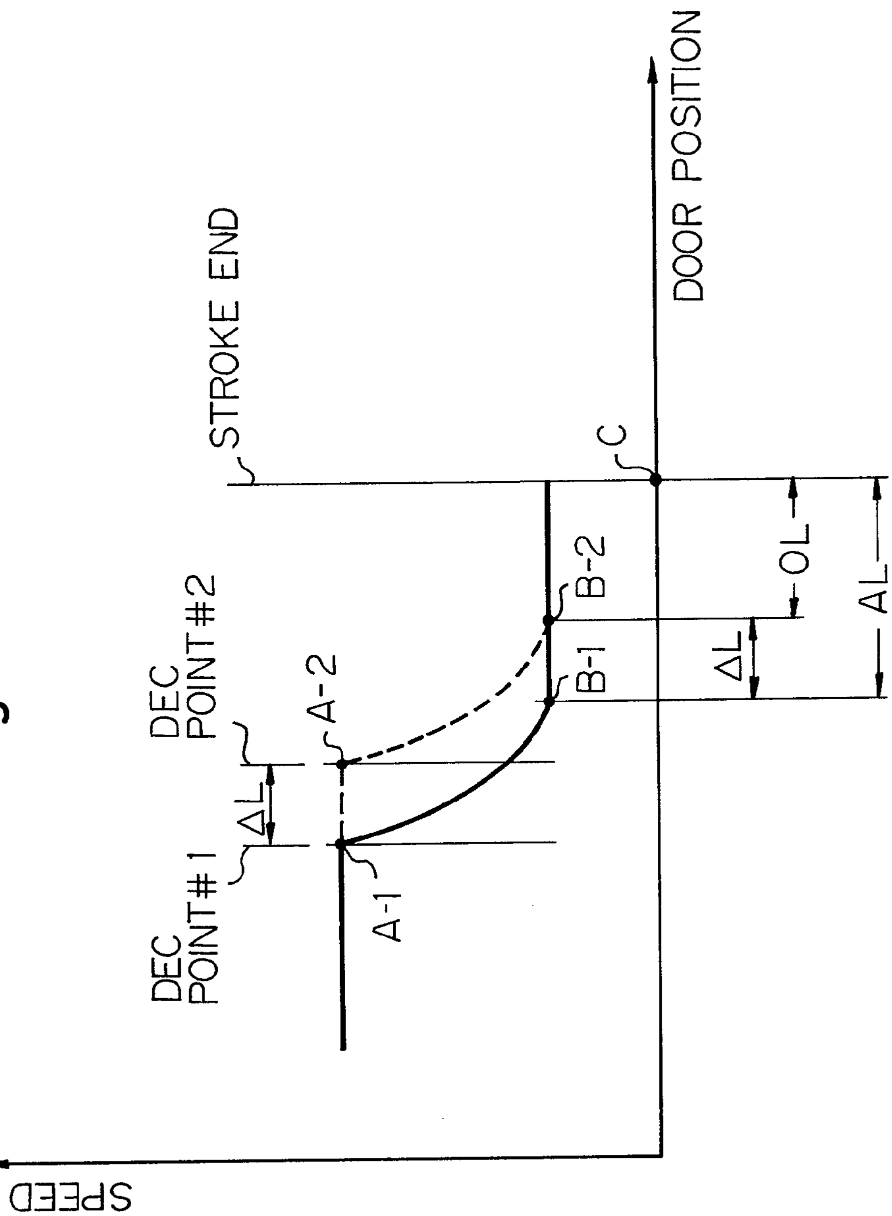


Fig. 9


STROKE END
DOOR POSITION
DEC POINT #2
DEC POINT #1
A-2
A-1
B-2
B-1
C
ΔL
OL
AL
SPEED

SPECIFICATION

Control apparatus for an automatic door with a minimum error in a detected door position

The present invention relates to an automatic door system, and more particularly to an apparatus for controlling such a system.

A typical automatic door system has a door coupled with and driven by a belt extending from a drive pulley to its driven pulley. The drive pulley is driven by a reversible motor. Controlled rotation of the reversible motor provides automatic opening and closing of the door. In the Japanese Patent Public Disclosures 19366/80 and 28982/81, there is disclosed a prior art apparatus for controlling such a door system which employs, as means for tracking the movement of a door, a revolution sensor mounted on the shaft of the door drive motor for generating signals indicating the number of revolutions of the motor.

However, the above sensing of the door movement is an indirect one, and ignores the error in the transmission mechanism from the motor to the door to be driven. For example, a slip sometimes occurs between the shaft of the motor and a transmission mechanism in the form of, example, a belt which extends to a drive pulley and/or between the drive pulley and a belt extending from the drive pulley and its driven pulley. Such slips introduce an error between the sensed door position and the actual door position. This might result in collisions of the door against its counterpart or a wall, or stopping of the door before it reaches its stroke end.

Further, continued running of the motor occurs when the transmission mechanism such as a belt is cut. This will burn the motor coils since the motor for driving a door is designed to be short-time rated.

In general, an automatic door should be decelerated to a low speed it reaches either of its stroke ends so that the door will have a smoothed stop action at the stroke end to prevent hazard.

For this purpose, it has been practiced to determine an optimal braking torque and an optimal deceleration point on the basis of the door weight and the mechanical sliding resistance of the door. The prior art control system employs a decelerating switch physically positioned at the determined deceleration point. The output signal of the switch is used to switch the system from a high speed mode of operation to a reduced speed mode.

However, the sliding resistance of a door not only depends on temperatures and wind pressure against the door but also varies with time due to such as deterioration of a guide rail for the door. This leads to variations in optimal braking torque and deceleration point. Therefore, in order to maintain an optimal performance of the door the prior art systems would require a troublesome manual adjustment by repositioning the decelerating switch mounted in the path of door each time the sliding resistance of the door changes. In actuality, repetitive adjustments of deceleration point following the change of sliding resistance are too much trouble for an operator to do. Thus, an optimal performance of the door through an extended time of period cannot be obtained.

According to one aspect of the present invention there is provided an apparatus for controlling an automatic door system in such a manner that the detected position of the door coincidences accurately with the actual position thereof.

According to another aspect of the present invention there is provided an apparatus for controlling an automatic door system which assures that any damaging collision of the door against its counterpart is to be avoided so that the door is moved smoothly between ends of its stroke.

According to another aspect of the present invention there is provided an apparatus for controlling an automatic door system which prevents overheating of a motor for driving the door by stopping the motor in cases where the coupling between the motor and transmission means in the form of, for example, a belt is disconnected.

According to another aspect of the present invention there is provided an improved apparatus for controlling the opening and closing of a door which does not require any switches or dogs physically positioned relative to the door, and which can maintain an optimal performance of the door operation irrespective of variations in the weight and/or sliding resistance of the door.

According to another aspect of the present invention there is provided an apparatus for controlling the opening and closing of a door in such a manner that the door operation cycle complete in a minimum time while providing a safety operation.

According to another aspect of the present invention, there is provided an apparatus for controlling the operation of an automatic door comprising: an electric motor; reciprocally movable driving means mechanically coupled with said motor and directly coupled to the door; sensing means disposed relative to said movable driving means for generating pulses having a pulse repetition rate in proportion to the speed or velocity of said movable driving means; door position detecting means electrically coupled with said sensing means for counting said pulses to obtain the current door position; and control means responsible to the obtained current door position for controlling the operation of said motor.

Preferably the above mentioned control means includes means for providing a deceler-

ation point associated with the door operation, means for comparing the current door position with the deceleration point to generate a low speed command upon the coincidence therebetween and pass it to speed control means for the motor, means for measuring a variable run-length of the door subject to variations in the mechanical condition of the door, means for setting a predetermined optimal low speed run-length over which the door is to run at a low speed until it reaches the end of door stroke (full open or closed), and means for correcting the deceleration point by utilizing the measured variable run-length and the optimal low speed run-length.

According to another aspect of the invention there is provided a door controlling system comprising a door, means for driving said door to run between ends of its stroke having final movable transmission means directly coupled to said door, and speed control means for controlling said driving means in such a manner that said door will be initially accelerated from one end of said stroke, then run at a high speed, then be decelerated, then run at a low speed, and finally stop at the other end of said stroke, thus completing one stroke operation of said door, the speed control means comprising:

sensing means disposed relative to said final movable transmission means for generating pulses having a pulse repetition rate in proportion to the velocity of the movement of said final transmission means;

door position detecting means for counting said pulses from said sensing means to obtain the current position of said door;

means for providing a deceleration point associated with said one stroke operation of said door; and

means electrically coupled with said speed control means for comparing said current position of said door with said deceleration point to generate a low speed command upon the coincidence of said current position with said deceleration point so that said speed control means will decelerate said door toward said low speed in response to the generation of said low speed command.

The present invention will be described by way of example with reference to the accompanying drawings, wherein:-

Figure 1 is a schematic and block diagram of an automatic door system embodying the present invention;

Figure 2 shows part of the system in Fig. 1 illustrating a speed control of a motor for driving the door;

Figure 3 is a perspective view of a sensor arrangement which senses the motion of a driving belt directly coupled with the door;

Figure 4 shows a circuit diagram of a speed sensing and direction determining circuit;

Figure 5 is a timing chart of the operation of the circuit shown in Fig. 4;

Figure 6 shows part of the system in Fig. 1 illustrating the main control;

Figure 7 shows a detailed block diagram of a modification of the main control shown in Fig. 6;

Figure 8 is a graphical representation of the door operation illustrating door running characteristics for different mechanical conditions of the door; and

Figure 9 is a graphical representation of the door operation illustrating the concept of automatic correction of deceleration point.

Fig. 1 is a diagrammatic view of an entire door control system. A motor designed by M is coupled with a drive pulley 2 through a belt (not shown) and a reduction gear 1. A belt 4 extends from the drive pulley 2 to a driven pulley 3 and is coupled to a door 5 by means of a coupling member 6. Therefore, a forward and reverse rotation of the motor M will provide an opening and closing of the door 5.

A tacho generator 7 in the form of an alternator is coupled with the motor M to produce an output signal which passes through a rectifier and ripple filter circuit 8 to a conventional speed control circuit 9. A sensor A in the form of such as a mat switch, a photoelectric tube and so on is adapted to detect the approach of a person to the door 5 to produce and supply a signal R_1 to the main control 11 which in turn will generate control signals to control the speed control circuit 9 to drive the motor M.

In accordance with an important aspect of the control system there is provided a door motion sensing means 10 disposed relative to the driving belt 4. The sensing means 10 operatively produce a sensed signal indicative of the motion of the driving belt and supplies it to the main control 12 through a speed and direction detector 11.

The details of each component will now be described.

As shown in Fig. 2, the tacho generator 7 is coupled to rotation axis of the motor M and generates an AC voltage in response to the rotation of the motor M. The generated voltage will increase and decrease in amplitude and frequency as the motor M runs at higher and lower speeds, respectively.

The rectifier and ripple filter circuit 8 comprises a diode bridge 13 adapted to provide a full-wave rectification of the output voltage from the tacho generator 7 and a ripple filter 14 adapted to obtain a smoothed DC voltage V_1. The output voltage V_1 is in proportion to the rotational speed of the motor M and is supplied to the speed control circuit 9.

The speed control circuit 9 includes an operational amplifier 15 adapted to amplify the differential voltage between the output voltage V_1 from the rectifier and ripple filter circuit 8 and a set voltage of V_H or V_L; V_H indicates a predetermined high speed while V_L indicates a predetermined low speed. The

output of the operational amplifier 15 is connected to a speed control pulse generator 17 adapted to generate pulses in accordance with the amplitude of the signal from the operational amplifier 15 and supply them to first and second AND gates 16_1 and 16_2. An operational amplifier 18 compares the output voltage V_1 from the rectifier and ripple filter circuit 8 with the set voltage of V_H or V_L and generates a braking signal when the voltage V_1 becomes higher than the set voltage. The braking signal is applied to a third AND gate 16_3 and also to a braking pulse generator 19 which responsively produces braking pulses and applies them to the third AND gate 16_3. A stop signal ST is used to operate a stop switch 20 so that the output voltage V_1 is grounded. A signal R_2 indicates a forward rotation of the motor M and is supplied to the first AND gate 16_1. A signal R_3 commands a reverse rotation of the motor M and is supplied to the second AND gate 16_2. The output signals from the first and second AND gates 16_1 and 16_2 are connected to first and second OR gates 21_1 and 21_2, respectively. The output signal from the third AND gate is connected to both the first and second OR gates 21_1 and 21_2. Thus, when the forward signal R_2 is generated, speed control pulses from the pulses generator 17 pass through the enabled first AND gate 16_1 and the first OR gate 21_1 to a gate electrode G_1 of a first triac 22_1 for forward rotation of the motor M. On the other hand, when the reverse signal R_3 is generated, speed control pulses from the pulse generator 17 pass through the enabled second AND gate 16_2 and the second OR gate 21_2 to a gate electrode G_2 of a second triac 22_2 for reverse rotation of motor M. In this manner, the motor M is controlled to selectively run at a high speed set by the voltage V_H or a low speed set by the voltage V_L and to be braked by the activation of the stop switch 20 in response to the stop signal ST so that the door 5 will correspondingly move at a high or low speed and will be stopped.

Fig. 3 shows an embodiment of the motion sensing means 10 disposed relative to the drive belt 4 directly coupled to the door for generating a signal indicative of the motion of the drive belt 4. The illustrated sensing means include two optoelectronic couplers each having an optical path across the width of the drive belt. The first optoelectronic coupler comprises a first light emitting device 40_1 and a first light receiving device 41_1 aligned with the light emitting device 40_1 along a first light path 42_1. Similarly, the second optoelectric coupler comprises a second light emitting device 40_2 and a second light receiving device 41_2 in aligment with the light emitting device 40_2 along a second light path 42_2. The illustrated drive belt 4 is a synchronous or timing belt having evenly spaced teeth 4T on the bottom surface thereof. The pitch between adjacent teeth is designated by P.

As shown in Fig. 3, the first optoelectronic coupler is spaced from the second optoelectric coupler by a distance L along the direction of reciprocal motion of the drive belt 4. The illustrated distance L is selected at $L = P \times n + P/4$ where P is the pitch between adjacent teeth of the bottom surface of the drive belt, and n is an integer (0, 1, 2 ...). Alternatively, the distance may be selected at $L = P \times n - P/4$. In other words, the first optoelectronic coupler is out of phase with the second optoelectronic coupler by ninety degrees in terms of cyclic profile defined by the teeth of the drive belt so that when the second light path 42_2 of the second optoelectronic coupler is aligned with the center 4b between adjacent teeth, the first optoelectric coupler is positioned at the boundary between a tooth and a space.

As shown in Fig. 4, each of the light emitting devices 40_1 and 40_2 includes a light emitting diode LED as a light source. Each of the light receiving devices 41_1 and 41_2 includes a light activated or photo transistor LATR. Output signals from the first and second photo transistors are connected to the speed and direction detector 11.

The speed and direction detector 11 includes a first one shot or monostable multivibrator 43_1 having an input coupled with the first photo transistor and an inhibit terminal INH coupled with the second photo transistor. The detector 11 also includes a second one shot or monostable multivibrator 43_2 having an input coupled to the first photo transistor via an inverter and an inhibit terminal INH coupled to the second photo transistor. Each of the one shots 43_1 and 43_2 operatively generates a single pulse having a definite duration in response to a pulse at its input; however, when there is a signal at its inhibit terminal INH, this inhibits the associated one shot from generating any pulse.

The output O of the first one shot 43_1 is connected to a set terminal s of a flip flop or bistable multivibrator 45 and to an input of a NOR gate 46. The output O of the second one shot 43_2 is connected to a reset terminal R of the flip flop 45 and to another input of the NOR gate 46. The flip flop 45 operatively determines the direction of movement of the door driving belt 4 from input conditions and generates a signal R/L indicative of the direction at its output Q to supply it to the main control 12. The NOR gate 46 operatively produces a train of pulses P_1 having a pulse repetition rate in proportion to the velocity of the door drive belt 4.

Fig. 5 shows a timing chart of the operation of the speed and direction detector circuit shown in Fig. 4.

When the drive belt 4 is moving in a direction as indicated by an arrow A (i.e.

when the door is being advanced towards its open position), the first and second photo detectors 41_1 and 41_2 generate pulses occuring in a period A as shown in a Fig. 5. It is noted that the pulses from the first detector 41_1 are out of phase with or lead the pulses from the second detector 41_2 by an angle of ninety degrees. Thus, in response to each positive-going transition of the pulses from the first photo detector 41_1, one shot 43_1 generates a single pulse having a definite duration at its output terminal O. However, the second one shot 43_2 is inhibited by a signal to its inhibit terminal from generating any pulse at its output terminal O.

Thus, the NOR gate 46 selects pulses from the first one shot 43_1 and supplies them to the main control. Similarly, flip flop 45 is set by a pulse from the first one shot to generate, at its output terminal O, a high level signal R indicative of the opening mode of the system operation (i.e. the door is being advanced toward a its open position).

Conversely, when the drive belt 4 is moving in an opposite direction as indicated by an arrow B in Fig. 4 (i.e. when the door is moving back to its close position), the first and second photo detectors 41_1 and 41_2 generate pulses occurring in a period B as shown in Fig. 5. In this case, the pulses from first detector 41_1 have a phase lag of ninety degrees relative to the pulses from the second photo detector 41_2. Thus, in response to each negative-going transition of pulses from the first photo detector 41_1 (each positive-going transition of pulses appearing at the input terminal I of the second one shot), the second one shot 43_2 generates a single pulse having a predetermined duration at its output terminal O. However, the first one shot 43_1 is inhibited since a high level or inhibit signal from the second photo detector 41_2 appears at the inhibit terminal INH of the first one shot 43_1 at the time of positive-going transition of the input signal thereto, thus disenabling the first one shot from being. Accordingly, the NOR gate 46 selects pulses from the second one shot 43_2 and supplies them to the main control, while flip flop 45 is reset by a pulse from the second one shot to generate at its output terminal O, a low level signal L indicative of the closing mode of the system operation (i.e. the door is moving back to its close position).

Referring now to Fig. 6, there the main control 12 is illustrated in greater detail. The main control 12 includes a door position measuring means 23 in the form of counter adapted to count pulses P_1 having frequencies in proportion to the speed of the reciprocal movement of the door driving belt 4. The overall operation of the main control 12 is controlled by a state sequencer 24 provided therein which selectively generates a series of commands and state signals to various components in and out of the main control 12 in a predetermined sequence. The main control 12 includes a door stroke setter 25 for setting a predetermined value of the stroke of the door to be used. The door stroke setter 25 supplies the set value of stroke to the door position counter 23. Since a complete cycle of door operation comprises a door opening operation during which the door moves from one end of stroke (fully closed) to the other end of stroke (fully open) and a door closing operation during which the door moves reversely, the main control 12 includes two channels one for handling the opening mode of operation and the other for handling the closing mode of operation. Among the first channel associated with the door opening mode are a deceleration point setter 26 for setting a deceleration point when the door moves forward to open and a comparator 28_1 for comparing the current door position from the counter 23 with the deceleration point from the setter 26. Similarly, the second channel associated with the door closing mode of operation comprises a deceleration point setter means 27 and a second comparator 28_2.

The main control further includes a pulse interval monitor or stroke end detector 29 which may comprise a counter for counting pulses form an oscillator therein adapted to generate pulses having a relatively high frequency. The counter counts pulses as supplied during one cycle of pulses P_1 having frequency in proportion to the speed of the door. When the count per cycle becomes greater than a selected value, the pulse interval monitor or stroke end detector 29 signals when the door reaches the end of stroke.

Finally, a gate circuit is provided which selectively supplies high and low speed commands H and L to the speed control 9. The illustrated gate circuit includes a first AND gate 30_1 adapted to receive the output of the first comparator 28_1 and a forward rotation command R_2 from the sequencer 24 and a second AND gate 30_2 adapted to receive the output of the second comparator 28_2 and a reverse rotation command R_3 from the sequencer 24. The outputs on the AND gates 30_1 and 30_2 are connected to the OR gate 31_2 which selectively generates and passes a low speed command L to the speed control 9. The output of the OR gate 31_2 is also connected via an invertor to one input of a third AND gate 30_3. The other input of the third AND gate 30_3 is connected to an OR gate 31_1 adapted to receive the forward and reverse rotation commands R_2 and R_3 from the sequencer 24. The third AND gate selectively generates and passes a high speed command H to the speed control 9.

The operation of the main control 12 will now be described.

When the sensor A detects the approach of a person to the door, it will generate a signal

R_1. Responsively, the state sequencer 24 generates a signal R_4 and supplies it to the counter 23 which in turn receives a signal indicative of a predetermined stroke length of the door as set in the stroke setter 25.

At the same time, the state sequencer 24 generates a door opening signal R_2 (command of the forward rotation of the motor) and supplies it to the speed control 9. The signal R_2 is further supplied to the first OR gate 31_1 and the third AND gate 30_3 which, in turn, generates a high speed command signal H and supplies it to the speed control 9 so that the motor will accelerate and run at a high speed indicated by the command signal H in a forward direction indicated by the forward command signal R_2. Thus, the door 5 will move at a corresponding high speed toward its open position.

The movement of the drive belt 4 in the direction A (corresponding to the opening direction of the door) is detected by the motion sensor 10 including two spaced photo transistors which generate first and second train of pulses having a phase relationship determined by the direction A of the belt movement. Thus, the speed and direction detector 11 determines that the door is moving toward its open position and supplies a direction signal R to put the door position counter 23 in the count down mode of operation. Further the speed and direction detector 11 selects the first train of pulses from the first photo transistor and supplies it as a train of pulses P_1 to the clock input to the door position counter 23. Responsively, the counter 23 counts the pulses P_1 down from the value of stroke set in the door stroke setter 25 to obtain the current position of the door. The results of the respective counting down operations by the counter 23 are successively supplied to the first comparator 28_1 which compares the successive position data each indicating the current position of the door with a deceleration point in the opening mode, as stored in the setter 26. When the current position coincides with the stored deceleration point, the first comparator 28_1 generates a signal and supplies it through the AND gate 30_1 enabled by the door opening signal R_2 to the second OR gate 31_2 to produce a low speed command signal L. Upon this signal, the motor M decelerates toward a selected low speed in a forward direction. The door 5 correspondingly is decelerated.

When the door 5 reaches a stroke end (full open), the pulse interval monitor 29 senses it by detecting an increased interval between pulses P_1 due to a decrease in the door speed, and signals to the sequencer 24. Responsively, the state sequencer 24 generates a stop command ST and supplies it to the speed control 9 by which the motor is stopped.

Then, in accordance with its sequential logic the state sequencer 24 generates a door closing command signal R_3 (command of the reverse rotation of the motor) and supplies it to the speed control 9. The signal R_3 is also supplied to the second AND gate 30_2 to put it in an enabled condition. Further, the signal R_3 is supplied through the first OR gate 31_1 to the third AND gate 30_3 which, in turn, generates a high speed command signal H and supplies it to the speed control 9. Accordingly, the motor will accelerate and run at a high speed indicated by the command signal H in a reverse direction indicated by the reverse command signal R_3. Thus the door will move at a corresponding high speed toward its close position.

The movement of the drive belt 4 in the direction B (corresponding to the closing direction of the door) is detected by the motor sensor 10. In response to the signals from the sensor 10, the speed and direction detector determines the direction of the movement of the door and supplies a signal L to put the door position counter 23 into the count up mode of operation. Further, the speed and direction detector 11 selects the second train of pulses from the second photo transistor and passes it as a train of pulses P_1 having a pulse repetition rate corresponding to the speed of the drive belt to the door position counter 23. Responsively, the counter 23 counts up the pulses to obtain the current position of the door.

Thereafter the high speed running of the door continues until the measured current position of the door coincides with a deceleration point in the closing mode, as stored in the setter 27. Then, the second comparator 28_2 generates a coincident signal which is passed through the second AND gate to the second OR gate which, in turn, generates and supplies a low speed command signal L to the motor speed control 9. The low speed running of the door under the command L continues until the door reaches the other end of stroke (full closed). Then, the motor and, therefore, the door are stopped, and the door operation is completed.

Before turning to Fig. 7 which shows the details of the main control 12, modification of Fig. 6 arrangement, it may be convenient to describe the ways in which mechanical condition of the door (e.g. sliding resistance of door) will affect the door operation.

Fig. 8 shows running characteristics of the door for different mechanical conditions. In a door opening (or closing) operation, the door starts at one end of its stroke (not shown in Fig. 8) and is accelerated to run at a high speed as indicated by a line *a* in Fig. 8. At a deceleration point as indicated by A, a low speed command is generated and fed to a door speed control as exemplified in Fig. 2, by which the door is decelerated toward a low speed indicated by the low speed command. At this point, it should be noted that the rate

of decrease of the door speed depends on the existing mechanical condition (e.g. sliding resistance) of the door. For a middle sliding resistance, the door will slow down with a middle rate of decrease as indicated by curve *b* in Fig. 8, and the run-length during a decelerating period will be a medium one as indicated by a length L_1 in Fig. 8. When the door reaches point B, the door speed is reduced to a low speed, and thereafter the door continues running at that low speed until it is stopped at the stroke end of the door as indicated by a point C. However, for higher sliding resistance, the door will be decelerated more quickly. Thus the door will follow a curve *b′* having greater rate of decrease before it comes to run at a low speed at a point B′. Correspondingly, the run-length during a deceleration period will be shorter as indicated by a length L_1'. On the other hand, for lower sliding resistance, the door will be decelerated gradually to make curve *b′* having a lower rate of decrease of speed before it comes to run at a low speed at point B″. Correspondingly, the deceleration run-length will be longer as indicated by a length L_1''.

It is understood that variation in sliding resistance leads to variations in run-length L_1 during a decelerating (transitory or settling time of) period during which the door is switched from a high speed to a stable low speed. If a deceleration point A is fixed relative to the end of stroke (i.e. distance L_3 as shown between the deceleration point A and stroke end C is constant), variations in decelerating run-length L_1 due to change in mechanical door conditions lead to variations in low speed run-length L_2 over which the door will run at a low speed. This would often require an unnecessarily long time to complete a door opening and/or closing cycle. Under some other circumstances, the door may collide with its counterpart or a wall. This is hazardous.

It is desirable that the deceleration point is automatically corrected each time that the door operation is performed. Fig. 9 is a graphical representation of the door operation illustrating the concept of automatic correction of deceleration point. During a first door opening (or closing) operation, the door is decelerated from a first decelerated point A-1. At a point B-1, the door is stabilized to run at a low speed. Means are provided which measure the actual length A_L from the point B-1 to the stroke end C over which length the door has run at a low speed. Means area also provided which store a predetermined optimal low speed run-length O_L. Comparing means compares the actual low speed run-length with the optimal low speed run-length to obtain the difference Δ_L therebetween. Correction is made to the deceleration point so that a new deceleration point A-2 is shifted from the old A-1 by the departure Δ_L of the actual low speed run-length from the optimal.

In the next or second door opening (or closing) operation, the door will change its speed at the new corrected deceleration point A-2. Since the mechanical condition of the door in the second door operation is generally similar to that in the first door operation as far as the second operation is done shortly after the first, the door will follow a similar decelerating curve. Thus, the decelerating motion of the door will complete at a point B-2 spaced from the point B-1 by a distance substantially equal to the departure Δ_L. In other words, the point B-2 is located at a position space from the stroke end by a distance nearly equal to the optimal low speed run-length O_L. Therefore, the actual low speed run-length in the second door operation would correspond substantially to the selected optimal low speed run-length.

Referring now to Fig. 7, there the main control 12 incorporating automatic deceleration point correction means is illustrated in greater detail. The main control 12 includes a door position measuring means 23 in the form of counter adapted to count pulses P_1 having frequencies in proportion to the speed of the reciprocal movement of the door driving belt 4. The overall operation of the main control 12 is controlled by a state sequencer 24 provided therein which selectively generates a series of commands and state signals to various components in and out of the main control 12 in a predetermined sequence. The main control 12 includes a door stroke setter 25 for setting a predetermined value of the stroke of the door to be used. The door stroke setter 25 supplies the set value of stroke to the door position counter 23 when enabled by a signal S_1 from the state sequencer 24. Since a complete cycle of door operation comprises a door opening operation during which the door moves from one end of stroke (fully closed) to the other end of stroke (fully open) and a door closing operation during which the door moves reversely, the main control 12 includes two channels one for handling the opening mode of operation and the other for handling the closing mode of operation. Among the first channel associated with the door opening mode are a deceleration point settable means 26 in the form of storage or register for storing a deceleration point when the door moves forward to open, an initial deceleration point setter 34 for providing an initial deceleration point used in the system, a comparator 28_1 for comparing the current door position from the counter 23 with the deceleration point from the register 26, and a corrector 23_1 in the form of arithmetic unit for correcting the deceleration point from the register 26 according to the deviation of the actual low speed run-length of the door from a preselected optimal low speed run-length. Similarly, the second channel as-

sociated with the door closing mode of operation comprises deceleration point settable means 27 in the form of storage or register, an initial deceleration point 35, a second comparator 28_2 and a second corrector 33_2. Each of the initial deceleration points provided by initialisers 34 and 35 is preferably chosen in view of safety to be remotest from the corresponding end of stroke than other possible deceleration points from the stroke end.

The main control 12 further includes low speed run-length measuring means including a low speed detector 38 and a pulse interval monitor or stroke end detector 37. Each of the detectors may comprise a counter for counting pulses from an oscillator 36 adapted to generate pulses having a relatively high frequency. The counter counts pulses as received during one cycle of pulses P_1 having frequency in proportion to the speed of the door. When the count per cycle becomes greater than a selected value, the low speed detector 38 signals when the door comes to run at a selected low speed. Similarly the stroke end detector 37 signals when the door reaches the end of stroke. The actual low speed run-length measuring means further include a counter 32 adapted to count pulses P_1 as received during the period between the time of the low speed detector 38 and the time of the stroke end detector 37 to obtain the actual low speed run-length.

The main control 12 further includes an optimal run-length setter 39 for providing a preselected optimal low speed run-length. Coupled with the optimal run-length setter 39 and the actual run-length counter 32 is third arithmetic means 33_3 preferably in the form of magnitude comparator for comparing the actual low speed run-length with the optimal low speed run-length to obtain the error or departure of the former from the latter. The value of departure is supplied to either of the correctors 33_1 and 33_2 which, in turn, corrects the deceleration point as mentioned.

Finally, a gate circuit is provided which selectively supplies high and low speed commands H and L to the speed control 9. The illustrated gate circuit includes a first AND gate 30_1 adapted to receive the output of the first comparator 28_1 and a forward rotation command R_2 from the sequencer 24 and a second AND gate 30_2 adapted to receive the output of the second comparator 28_2 and a reverse rotation command R_3 from the sequencer 24.The outputs of the AND gates 30_1 and 30_2 are connected to the OR gate 31_2 which selectively generates and passes a low speed command L to the speed control 9. The output of the OR gate 31_2 is also connected via an invertor to one input of a third AND gate 30_3. The other input of the third AND gate 30_3 is connected to an OR gate 31_1 adapted to receive the forward and reverse rotation commands R_2 and R_3 from the sequencer 24. The third AND gate selectively generates and passes a high speed command H to the speed control 9.

The operation of the main control 12 in Fig. 7 will now be described.

When the circuitry activated up, the state sequencer 24 generates signals S_2 and S_3 which are supplied respectively to the initial deceleration point setter 34 (for opening) and 35 (for closing). Thus, the contents thereof are set into the deceleration point (used in the opening mode of the door) register 26 and the deceleration point (used in the closing mode of the door) register 27.

Thereafter, when the sensor A detects the approach of a person to the door, it will generate a signal R_1. Responsively, the state sequencer 24 generates a signal S_1 and supplies it to the counter 23 which in turn receives a signal indicative of a predetermined stroke length of the door as set in the stroke setter 25.

At the same time, the state sequencer 24 generates a door opening signal R_2 (command of the forward rotation of the motor) and supplies it to the speed control 9. The signal R_2 is further supplied to the first OR gate 31_1 and the third AND gate 30_3 which, in turn, generates a high speed command signal H and supplies it to the speed control 9 so that the motor will accelerate and run at a high speed indicated by the command signal H in a forward direction indicated by the forward command signal R_2. Thus, the door 5 will move at a corresponding high speed toward its open position.

The movement of the drive belt 4 in the direction A (corresponding to the opening direction of the door) is detected by the motion sensor 10 including two photo transistors which generate first and second train of pulses having a phase relationship determined by the direction A of the belt movement. Thus, the speed and direction detector 11 determines that the door is moving toward its open position and supplies a direction signal R to put the door position counter 23 in the count down mode of operation. Further, the speed and direction detector 11 selects the first train of pulses from the first photo transistor and supplies it as a train of pulses P_1 to the clock input to the door position counter 23. Responsively, the counter 23 counts the pulses P_1 down from the value of stroke set in the door stroke setter 25 to obtain the current position of the door.

The results of the respective down counting operations by the counter 23 are successively supplied to the first comparator 28_1 which compares the successive position data each indicating the current position of the door with a deceleration point in the opening mode, as stored in the register 26. When the current position coincides with the stored deceleration point, the first comparator 28_1 gen-

erates a signal and supplies it through the AND gate 30_1 enabled by the door opening signal R_2 to the second OR gate 32_2 to produce a low speed command signal L. Upon this signal, the motor M decelerates toward a selected low speed in a forward direction. The door 5 correspondingly is decelerated.

Pulses P_1 derived from the speed detector 11 are also fed to the low speed detector 38, the stroke end detector 37 and the low speed run-length counter 32. The low speed detector 38 counts reference pulses from the oscillator 36, as received during one cycle of pulses P_1. When the count per cycle becomes greater than a selected value, the low speed detector 38 generates a signal indicating when the door 5 comes to run at a selected low speed.

Accordingly, as the door 5 is decelerated in response to the generation of the low speed command L and comes to move at a relatively stabilized low speed, the low speed detector 38 signals it to the status sequencer 24. Responsively, the sequencer 24 generates a signal S_4 to enable the low speed run-length measuring counter 32 to count pulses P_1.

When the door reaches a stroke end (full open), the stroke end detector 37 senses it in a similar manner as the low speed detector 38 and signals to the sequencer 24. Responsively, the state sequencer 24 generates a stop command ST and supplies it to the speed control 9 by which the motor is stopped. Then, the sequencer 24 generates a signal S_7 to the third arithmetic means 33_3 to enable it to perform the comparison between the actual low speed run-length count from the measuring counter 32 with a predetermined optimal low-speed run-length from the optimal run-length setter 39. Then, the sequencer 24 generates a clear signal S_4 to clear the counter-type measuring counter 23.

The differential signal between the actual and optimal low speed run-length as resulted from the third arithmetic means 33_3 is applied to the first corrector 33_1 when enabled by a signal S_8 from the sequencer 24. Then, the first corrector 33_1 compares the differential signal indicating a value of deviation of the actual low speed run-length from the optimal low speed run-length with the deceleration point stored in the register 26 to subtract the latter from the former to provide a corrected decleration point and transfer it back to the register 26 under the control of a signal S_6 from the sequencer 24.

Instead of subtracting all the deviation of the actual low speed run-length from the optimal low speed run-length, correction can be made by multiplying the deviation value by a factor of less than unity to provide a reduced deviation and use it as a correction factor to be subtracted from the deceleration point. With this technique, corrections of the deceleration point are performed bit by bit, thus providing stabilization.

In the above, the measuring counter 32 measures the actual low speed run-length over which the door 5 has travelled at a low speed to the end of stroke. Alternatively, the counter 32 may measure the decelerating run-length over which the door 5 has moved from a high speed operation switched to a stable low speed operation. This can be achieved by starting the counting of pulses P_1 upon the generation of low speed command L as applied from the comparator 28_1 and continuing counting until the low speed detector 38 senses when the door comes to move at a relatively stable low speed.

Along with such a decelerating run-length measuring means, a suitable modification will be made to the correction logic of deceleration point. The correction may be performed by an arithmetic unit for combining the measured decelerating run-length with the optimal low speed run-length by, for example, adding the former to the latter.

It will be understood that the main control 12 in Fig. 7 calculates the deviation of the actual low speed run-length from the optimal low speed run-length for each cycle of door operation, and corrects the deceleration point on the basis of the calculated deviation so that the corrected deceleration point will match the current condition of the door weight and the sliding resistance of the door. The braking torque generated by the motor is assumed to be substantially constant.

When the door 5 is opened again upon the next approach of a person, the settable device has already stored an updated decelerating point so corrected as to meet the door weight and the sliding resistance of the door, no manual adjustment of the decelerating point will be required. This arrangement assures that an optimal automatic door operation is performed.

When the signal R_1 indicative of the presence of a person by the door is removed, the state sequencer 24 generates a door closing command R_3 (reverse rotation of the motor) is applied to the second AND gate 30_2 and the speed control 9. Responsively, the speed control 9 causes the motor 5 to accelerate to a high speed in a reverse rotation.

Since the operation of the main control 12 to perform a door closing operation is generally similar to the above-described operation except that components (28_2, 33_2, 27, 35, etc.) associated with the door closing operation are used, further description thereof will be omitted.

As is noted from the above, the illustrated door control systems employ drive belt motion sensing means for generating pulses having a pulse repetition rate in proportion to the speed of the drive belt 4 which is "directly" coupled to the door as a final load to be controlled,

and door position measuring means for counting such pulses to obtain the current position of the door. Therefore, the measured position of the door 5 coincides accurately with the actual door position. In particular, the measured door position signal does not include any error associated with a slip in a transmission mechanism between the motor and the reduction gears and a slip between the drive pulley and the drive belt. Thus collision of the door with the counterpart and/or premature stop of the door before it reaches the stroke end can be avoided so that a smooth operation of opening and closing the door may be attained.

Further, the motion sensing means (light emitting device 40 and receiving device 41) may be placed at any position in a reciprocally moving stroke or path of the drive belt 4. This will minimize the length of electric wires for connecting the motion sensing means to the speed and direction detector 11 since both of them may be built in or placed near a controller including the main control 12 disposed near the drive belt, and simplify the connection work associated therewith.

The direction detector determines whether the door is moving toward either its open position or close position. This will simplify the sequence logic used in the state sequencer 24.

In case, for example, that the door drive belt and the door are erroneously stopped because the drive belt is accidentally disengaged from the drive pulley, this is positively sensed by the pulse interval monitor 29 in cooperation with the motion sensing means and speed and direction detector, and conditions the sequencer 24 to generate a stop command ST, thus stopping the motor which would otherwise run continuously and be overheated.

Whereas a timing belt is preferred as the transmission means 4, other transmission means such as V-belt, flat belt and chain can be substituted.

Whereas the illustrated motion sensor 10 comprises optoelectronic devices, other sensing technique such as the use of magnetic sensors, contact-type sensors and iron segment sensors may be employed.

In brief, the motion sensing means may be implemented by any conventional sensor. However, it is important that such a sensor be disposed relative to a door driving member (e.g. drive belt 4) directly coupled to the door and operatively generate a signal in the form of, for example, a train of pulses having pulse repetition rate accurately in proportion to the speed of the movement of the door driving member.

Further the arrangement in Fig. 7 does not require any members such as switches and dogs physically placed relative to the door and always performs an optimal automatic door operation irrespective of variations of the door weight and the sliding resistance of the door without requiring any manual adjustment of the deceleration point.

While the present invention has been described with respect to the illustrated embodiments, it is to be construed that various other modifications and variations can be made well within the scope of the invention as defined in the appended claims.

CLAIMS

1. An apparatus for controlling the operation of an automatic door comprising:

an electric motor;

reciprocally movable driving means mechanically coupled with said motor and directly coupled to the door;

sensing means disposed relative to said movable driving means for generating pulses having a pulse repetition rate in proportion to the speed or velocity of said movable driving means;

door position detecting means electrically coupled with said sensing means for counting said pulses to obtain the current door position; and

control means responsive to the obtained current door position for controlling the operation of said motor.

2. An apparatus as claimed in claim 1 wherein said movable driving means comprises a drive belt directly coupled to the door and extending from a drive pulley to a driven pulley.

3. An apparatus as claimed in claim 2 wherein said drive belt is a synchronous belt having equally spaced teeth on the bottom surface thereof.

4. An apparatus as claimed in claim 3 wherein said sensing means comprise a pair of optoelectric couplers spaced from each other in the direction of the movement of said synchronous belt, the light from the light emitting portion to the light receiving portion of each of said optoelectronic couplers being intermittently interrupted by successive teeth of said synchronous belt in response to the movement thereof.

5. An apparatus as claimed in claim 4 wherein the first of said optoelectric couplers operatively produces pulses having a first predetermined phase relationship with the phase of pulses produced by the second of said optoelectronic couplers in response to the movement of said synchronous belt in a forward direction while said first optoelectronic coupler produces pulses having a second predetermined phase relationship, distinguishable from said first phase relationship, with the phase of pulses produced by said second optoelectronic couplers in response to the movement of said synchronous belt in a reverse direction.

6. An apparatus as claimed in Claim 5

further including direction detecting means coupled with said pair of optoelectronic couplers for determining the direction of movement of said sychronous belt from the sensed phase relationship between pulses from the first and second optoelectronic couplers.

7. An apparatus as claimed in Claim 1 further including pulse interval monitor means for monitoring an interval between adjacent pulses from said sensing means and selectively generating a signal indicating that the interval has become greater than a predetermined length of time wherein said control means responds to said signal from said pulse interval monitor means to produce a stop command signal for said motor, thus avoiding the overheating of said motor which would be encountered in case that the transmission means from said motor to the door is disconnected.

8. A door controlling system comprising a door, means for driving said door to run between ends of its stroke having final movable transmission means directly coupled to said door, and speed control means for controlling said driving means in such a manner that said door will be initially accelerated from one end of said stroke, then run at a high speed, then be decelerated, then run at a low speed, and finally stop at the other end of said stroke, thus completing one stroke operation of said door, the speed control means comprising:

sensing means disposed relative to said final movable transmission means for generating pulses having a pulse repetition rate in proportion to the velocity of the movement of said final transmission means;

door position detecting means for counting said pulses from said sensing means to obtain the current position of said door;

means for providing a deceleration point associated with said one stroke operation of said door; and

means electrically coupled with said speed control means for comparing said current position of said door with said deceleration point to generate a low speed command upon the coincidence of said current position with said deceleration point so that said speed control means will decelerate said door toward said low speed in response to the generation of said low speed command.

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